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TECHNICAL REPORT 85-1

LABORATORY TRIALS OF STEEL-FIBER REINFORCED CONCRETE

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LABORATORY TRIALS
OF
STEEL-FIBER REINFORCED CONCRETE

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ABSTRACT

This report contains the results of an evaluation of fiberous (steel-fiber-reinforced) concrete utilizing a newly designed steel fiber. The study consisted of laboratory work which included mix designs, with various percentages of steel fibers, and strength testing.

No balling of the fibers was observed during mixing as in previous department experience. However, the workability of the concrete decreased as more fibers were added. The fiberous concrete did not exhibit a consistent flexural strength gain over the control concrete as claimed by the fiber manufacturer.

Based on laboratory results no general use is recommended, except for special usage such as slope stabilization.

INTRODUCTION

This study was undertaken to evaluate Dramix Steel Fibers, which when added to normal concrete, are claimed to increase the concrete's strength. The manufacturer, Bekaert Steel Corporation, Niles, Illinois, also claims that in many cases steel mesh reinforcing, used to control cracking, could be eliminated.

Fiberous concrete is a composite material composed of conventional Portland cement concrete with steel fibers randomly dispersed throughout. The fibers are intended to act as arresters, restricting the growth of cracks in the concrete matrix and preventing their enlargement under stress into cracks that could cause failure.[1]

Previous Department experience with fiberous concrete has been disappointing. In 1973, the Materials Bureau conducted a four phased experimental study consisting of laboratory work, trial plant batching, construction of a bridge deck overlay, and post-construction inspection. The results of this study (Materials Bureau Technical Report No. 18) were published in April 1975. As stated in this report, problems occurred during mixing the fibers into the concrete. This resulted in large fiber balls forming in the concrete. Eventually, this problem was solved, although the mixing procedure was slow. Post-construction inspections revealed fiber-related spalling (popouts) and shrinkage cracks. These problems combined with less than expected ultimate strength results in the lab and field, led to the Materials Bureau discontinuing further experimental work with fiberous concrete.

Bekaert Corporation claims when the proper mix design and procedures are used their fibers do not ball when dumped in the mixer, distribution is uniform throughout the mix, workability and handling are excellent, and no special equipment is required for mixing. They noted some projects will require less concrete. The design of the Stapleton International Airport overlay in Denver called for 15 inch thick concrete runways, however with the addition of fibers, the thickness was reduced to 7 or 8 inches. This resulted in an eventual savings of $1 million.

LAB TRIALS OF STEEL-FIBER REINFORCED CONCRETE

Comparison tests were done using a conventional Class E concrete mix with and without fibers.

NYSDOT Class E concrete is a 6.9 - bag/yd^3 mix normally used in the construction of structural slabs and structural approach slabs.

Two sets of four concrete mixes were done in the lab. One set using fibers 50 millimeters (ZP 50/.50) long and the second set using fiber 30 millimeters (ZP 30/.50) in length. Both types of fibers were 0.5 millimeters in diameter. The first mix of each set, the standard mix design for Class E concrete, was used as a control, while the second, third, and fourth mixes were the same mix design with the addition of 50, 60, or 70 pounds per cubic yard of the fibers. A horizontal drum concrete mixer with counter-rotating paddles was used. The mix designs are in Table 1.

TABLE 1 MIX PROPORTIONS PER CUBIC YARD

QUANTITY	MIX A	MIX B	MIX C	MIX D
Portland Cement (Type II), lb.	648	648	648	648
Fine Aggregate, lb. (Saturated Surface Dry) (Fineness Modulus = 3.039)	980	980	980	980
Coarse Aggregate, lb. (Saturated Surface Dry)	2006	2006	2006	2006
Water, lb.	285	285	285	285
Steel Fibers, lb. (ZP 50/.50) 50 mm length, 0.5 mm diameter	0	50	60	70

QUANTITY	MIX E	MIX F	MIX G	MIX H
Portland Cement (Type II) lb.	648	648	648	648
Fine Aggregate, lb. (Saturated Surface Dry) (Fineness Modulus = 2.955)	1079	1079	1079	1079
Coarse Aggregate, lb. (Saturated Surface Dry)	1906	1906	1906	1906
Water, lb.	285	285	285	285
Steel Fibers, lb. (ZP 30/.50) 30 mm length, 0.5 mm diameter	0	50	60	70

NOTE: Differences in amount of Fine aggregate result from corrections for fineness modulus.

RESULTS

Bekaert claims to have eliminated the mixing and subsequent fiber balling problems, which are caused by a high aspect ratio (L/D). These problems are aggravated with increasing amounts of fibers in the mix. To prevent these problems, Bekaert collates (glues together) the hard drawn steel fibers, which are crimped at each end (refer to Appendix) and have an aspect ratio of up to 100, into clips of 30 fibers each. This creates an "artificial" low aspect ratio. When the clips are placed in the mix, the glue holding the fibers together dissolves, the fibers separate, and distribute evenly throughout the mix.

Results from the lab work support these claims. The mixing procedure consisted of cement, coarse and fine aggregate placed in mixer and mixed for 5 to 10 seconds. The water, air-entraining agent, and fibers were then added and the batch was mixed for 3 minutes, stalled for 3 minutes and mixed for 2 additional minutes. The glue dissolved and the fibers dispersed evenly throughout the mix within 30 seconds. No fiber balls appeared in any batches.

The slump and air content of the concrete mixes were affected by the addition of the steel fibers. With each increase in steel fibers, there was a reduction in the slump and air content. It should be noted that for the sake of consistency, no readjustments to the mix were attempted to alter slump and air content. These results are in Table 2.

TABLE 2 SLUMP AND AIR CONTENT

ZP 50/.50	DESIGN	MIX A (Control)	MIX B ($50 lbs/yd^3$)	MIX C ($60 lbs/yd^3$)	MIX D ($70 lbs/yd^3$)
Slump, in.	3-4	2.5	1.25	0.25	0
Air Content, %	6.0	4.8	4.8	4.5	4.2

ZP 30/.50	DESIGN	MIX E (Control)	MIX F ($50 lbs/yd^3$)	MIX G ($60 lbs/yd^3$)	MIX H ($70 lbs/yd^3$)
Slump, in.	3-4	3	2.75	2.25	2.0
Air Content, %	6.0	8.0	6.8	7.0	6.5

From each mix, two 6 by 12 inch cylinders were cast and tested for compressive strength at 7 and 28 days. These results are in Table 3. Also, four 3 by 4 by 16 inch prisms were cast and tested for flexural strength (ASTM C-78, Third Point Loading), at 7 and 28 days. These results are in Table 4. The manufacturer claims a two to three fold increase in ultimate flexural strength. The tests results are inconsistent and cannot support this statement.

TABLE 3 COMPRESSIVE STRENGTH

MIX	COMPRESSIVE STRENGTH (PSI)	
ZP50/.50	7-DAY	28-DAY
A (Control)	4220	5560
B (50lb/yd^3)	4340	5410
C (60lb/yd^3)	4450	5840
D (70lb/yd^3)	4500	5900
ZP30/.50	7-DAY	28-DAY
E (Control)	3450	4400
F (50lb/yd^3)	3460	4290
G (60lb/yd^3)	3600	4850
H (70lb/yd^3)	3550	4920

NOTE: ZP50/.50 - 50MM FIBERS/.5MM dia.
ZP30/.50 - 30MM FIBERS/.5MM dia.

Subsequent examination of the the tested prisms revealed a distinct difference between low and high strength prisms of the same fiber percentage. The concentration of steel fibers across the prisms' fracture faces is greater in the higher strength prisms. In these cases the fibers are doing what they are supposed to, increasing the concrete strength. It appears that fiber concentration consistency throughout the prism cannot be guaranteed from one prism to the next, even though lab procedures are the same. If this problem is not solved and extends to field operations, this lack of consistency would cause problems, e.g. weak areas within the concrete.

However, one advantage did appear during strength testing of the prisms. In testing the concrete prisms containing fibers 50 millimeters long, the fibers behaved in a way similar to steel-reinforcing mesh. The fibers held the concrete together as it cracked. This tendency would be helpful in procedures such as slope stabilization.

<u>TABLE 4 FLEXURAL STRENGTH</u>

MIX	ASTM C-78 FLEXURAL STRENGTH (PSI)	
ZP50/.50	7-DAY	28-DAY
A (Control)	620	875
	645	850
B (50lb/yd^3)	815	795
	655	680
C (60lb/yd^3)	792	990
	680	770
D (70lb/yd^3)	598	780
	885	755

MIX	ASTM C-78 FLEXURAL STRENGTH (PSI)	
ZP30/.50	7-DAY	28-DAY
E (Control)	610	765
	660	750
F (50lb/yd^3)	565	780
	650	700
G (60lb/yd^3)	675	740
	785	865
H (70lb/yd^3)	655	820
	625	875

A representative of Dramix was then notified and informed of the testing procedures and less than expected results. The representative suggested retesting for flexural strength using 6 x 6 x 18 inch specimens as mentioned in ACI Journal, Technical Paper No. 79-14, "Steel Fiber Reinforced and Plain Concrete: Factors Influencing Flexural Strength Measurement," rather than the 3 x 4 x 16 inch that were tested.

In addition to altering the specimen size and retesting the two sizes of Dramix fibers (ZP50/.50 and 30/.50), a new size of Dramix fiber would be tested. The new fiber, ZP60/.80, was 60 millimeters long and 0.80 millimeters in diameter. The fiber shape was the same as the previous two types.

The retesting followed the same formula as in Table 1. The amount of fibers remained the same at 50, 60, and 70 pounds per cubic yard. The flexural strength test specimen size was changed to 6 x 6 x 30 inches using an 18 inch test span (ASTM C-78, Third Point Loading).

Upon examination of the tested prisms, the same problem of inconsistent fiber concentration across the fracture faces recurred. As in the previously tested prisms, it becomes obvious that fiber concentration consistency throughout the prism cannot be guaranteed from one prism to the next.

Again the results were unimpressive. All three types of fibers failed to give a consistent increase in compressive and flexural strength as claimed by the manufacturer. The compressive strength results are in Table 5 and the flexural strength results are in Table 6.

TABLE 5 COMPRESSIVE STRENGTH

MIX	COMPRESSIVE STRENGTH (PSI)	
ZP50/.50	7-DAY	28-DAY
I (Control)	3550	4930
J (50lb/yd^3)	4000	5140
K (60lb/yd^3)	3750	5140
L (70lb/yd^3)	4090	5400
ZP30/.50	7-DAY	28-DAY
M (Control)	3760	4800
N (50lb/yd^3)	3440	4680
O (60lb/yd^3)	3790	4910
P (70lb/yd^3)	3710	5020
ZP60/.80	7-DAY	28-DAY
Q (Control)	3750	5340
R (50lb/yd^3)	3670	4910
S (60lb/yd^3)	4030	5200
T (70lb/yd^3)	3950	5550

NOTE: ZP50/.50 - 50MM FIBERS/.5MM dia.
ZP30/.50 - 30MM FIBERS/.5MM dia.
ZP60/.80 - 60MM FIBERS/.6MM dia.

TABLE 6 FLEXURAL STRENGTH

MIX	ASTM C-78 FLEXURAL STRENGTH (PSI)	
ZP50/.50	7-DAY	28-DAY
I (Control)	604	734
J (50lb/yd^3)	648	811
K (60lb/yd^3)	668	796
L (70lb/yd^3)	673	719
ZP30/.50	7-DAY	28-DAY
M (Control)	648	682
N (50lb/yd^3)	625	696
O (60lb/yd^3)	626	736
P (70lb/yd^3)	593	625
ZP60/.80	7-DAY	28-DAY
Q (Control)	550	738
R (50lb/yd^3)	627	716
S (60lb/yd^3)	597	771
T (70lb/yd^3)	645	686

RESULTS

1. No balling of fibers occurred even though they were added prior to mixing. Workability and handling of the mixes containing fibers was acceptable.

2. Loss of slump and workability occurred in the mixes as increasing amounts of fibers were added.

3. The mixes containing fibers showed the ability to control cracking and hold cracked concrete together.

4. While the mixes containing fibers achieved a maximum increase in flexural strength of 12% over normal concrete, this does not support claims by the manufacturer of a two to threefold increase.

RECOMMENDATIONS

Due to marginal performance, no general use is recommended. However, specialized usage in concrete slope protection would be beneficial.

REFERENCES

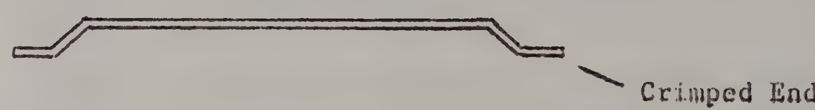
1. Giles, Keith "An Experimental Steel-Fiber-Reinforced Concrete Bridge Deck Overlay" Technical Report No. 18, New York State Department of Transportation Materials Bureau, April 1975.

2. Bekaert Steel Wire Corporation "Dramix Steel Fibers, The Miracle in the Mix".

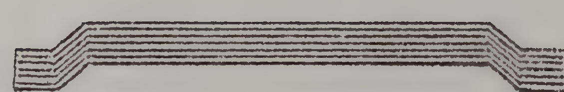
3. Coyle, W. V., Kulandaisamy, V., Ramakrishnan, V., and Schrader, E.K., "Performance Characteristics of Fiber Reinforced Concretes with Low Fiber Contents" ACI Journal 78-35, September-October 1981.

4. ACI Committee 544, "State-of-the-Art Report on Fiber Reinforced Concrete" ACI Report No. 544.1R-82, 1982.

APPENDIX



Individual Steel Fiber
30 or 50 mm. length
0.5 mm. diameter



Collated Fiber Clip